# Performance Enhancement of IEEE 802.11s Mesh Networks using Aggressive Block Ack Scheme

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***Abstract*—Enhanced distributed channel access (EDCA), a medium access function of the IEEE 802.11e, has been suggested for applying in the IEEE 802.11 based wireless mesh network (WMN). The block acknowledgement (Block ACK) feature of EDCA can be applied for the communication between the WMN nodes to overcome overheads by reducing the number of control packets for multiple data transmission. However, using block ACK, the performance in terms of throughput might degrade due to the presence of hidden/exposed nodes. Lengthy medium reservation by communicating nodes and lack of proper knowledge of ongoing transmission in neighboring nodes leads to under-utilized resources. Additionally, fairness among the nodes is another problem in the block ACK scheme. In this paper we introduce a simple but effective method to tackle the hidden/exposure terminal problem thus increasing the performance in terms of throughput and fairness.**

## I. Introduction

The wireless mesh network (WMN) [1] is considered to be one of the key player in the next generation wireless technology. The widespread applications along with availability of cheap and reliable products such as IEEE 802.11 enabled network interface card (NIC) has opened a big market for WMN [2]. The services provided by such devices are within the infrastructure based system and ad-hoc system where the devices can instantly communicate with other devices. WMNs are self-configured and self-organized networks with nodes having capability of automatically establishing the connection with the mesh in an ad-hoc mode [3].

Mesh gateway nodes, mesh points (MP), mesh access points (MAP) and wireless clients are the main elements of WMN. While the gateway nodes are connected with the wired network, all the other elements of the WMN are connected with each other through wireless medium. Each mesh node can also operate as a mesh router as needed for forwarding the packets to its destination. Mesh access point (MAP) is the main association to the wireless clients for the access to the networks.

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The wireless LAN (WLAN) mesh standard (IEEE 802.11s) incorporates medium access control mechanism from the IEEE 802.11e [4]. The quality of support (QoS) of IEEE 802.11e introduces the hybrid coordination function (HCF). HCF has two medium access mechanisms - the contention-based channel access known as enhanced distributed channel access (EDCA) and the controlled channel access known as HCF controlled channel access (HCCA). The EDCA uses distributed and contention based access for ad-hoc and mesh network environments. The drawback of EDCA is that the station cannot reserve the medium and access the medium without contending [5].

The burst acknowledgement (burst ACK) schemes [6] basically uses both contention period (CP) and contention free period (CFP) to access the channel. This avoids multiple RTS/CTS packets transmission for multiple data packets. In burst ACK, the nodes reserve the time period for data transmission - this is known as the transmission opportunity (TXOP). Within this TXOP, each data packet is immediately acknowledged after a successful transmission.

The motivation of the work came from the classical hidden/exposed terminal problem. The issue in this particular case is that the waiting time of the terminals is longer due to the TXOP. Communication using these hidden/exposed MAPs is not possible as it can affect the ongoing transmission. These MAPs needs to have the TXOP information in order to plan for the communications whenever required. This waiting for the channel can lead to the unfairness problem in the neighboring MAPs. Our main work is concerned with the enhancing the block ACK scheme to disseminate the information among the neighboring MAPs for proper scheduling of their packets which increases the throughput and decrease delay in the network.

## II. Background and Related Work

### A. Brief Overview on IEEE 802.11e Block Ack Scheme

Basically the block ACK scheme is reservation of the transmission channel for the multiple data transmissions without an immediate acknowledgement separated by the short inter-frame space (SIFS) time period. The single acknowledgement packet, block ACK (BA), is send by a receiver for a block of data packets transmitted by the source within TXOP time

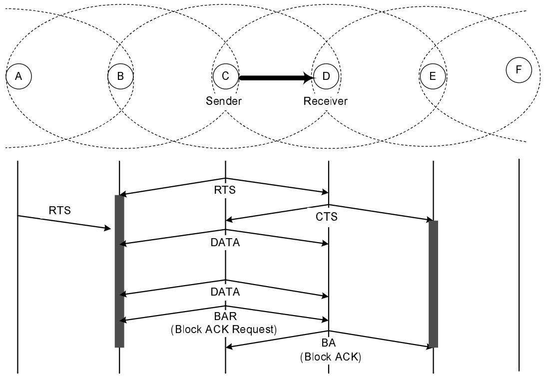



Fig. 1: IEEE 802.11e Block ACK scheme

period. On receiving the BA successfully the station waits for arbitrary inter-frame space (AIFS) interval before contending for next transmission.

In IEEE 802.11e, the access point (AP), periodically broadcast the start time of the communication by any nodes and block size to all of the stations. This is the setup mode for the block ACK where add block ACK (ADDBA) request and response message is exchanged between the nodes. Node C initiates the communication with node D by exchanging RTS/CTS packets as shown in Fig.1. Both the source and destination are aware of the TXOP limit which is periodically broadcasted by the AP. This RTS packet is also received by node B to lock the node for future communication for the safety of data. The CTS packet transmitted by node D to node C is also received by node E, which starts the network allocation vector (nav) timing. Beside these, no other nodes will be active for the communication. After transmission of multiple data packets, block ACK request (BAR) is send to destination and in response block ACK (BA) is send back to inform the status of individual data packets. Failure in receiving data packets results in using successive TXOP to retransmit the data in block or individual transmission. The block ACK (BA) response can be one of following policies negotiated by the nodes in setup mode.

*1) Immediate block ACK policy:* The BAR frame is immediately responded with a block ACK frame. The source updates its records depending upon the status on BA sent by the destination. The corrupted data packets are collected and transmitted in a block or individually depending upon the setup. These transmission could be for the corrupted data packets or with the fresh data packets as well depending upon the setup. For this transmission also the node should reserve transmission time in subsequent TXOPs.

*2) Delayed block ACK policy:* In this policy the destination node responds to the BAR packet with the ACK frame only. The destination needs to send its BA response in the subsequent TXOP. Destination node should send this BA packet with very high priority. The source node should record BA for all the sent packets within that TXOP and retransmit any corrupted packets within next TXOP in block or individually.

Block ACK scheme is effective in enhancing the performance of the network. With the new idea and modification in EDCA, the time critical data can also be sent through the network without degradating the performance by giving different priorities to the data packets depending upon the condition. This scheme however has a problem which is widely known as the exposed/hidden terminal problem. Here the problem is severe when the reservation of the channel by the communicating nodes are longer as the neighbor nodes need to wait for a longer time period. As in Fig. 1, when node A wants to initiate the communication within the ongoing communication, it fails to do so as node B will not reply to its RTS. This will update the backoff timer and the time period could go to the highest value. This also creates a new problem which is known as fairness as it cannot access the channel after going to backoff state even if the channel is free. First it finishes the backoff timer and then contend for the channel access. If another node contends and wins the channel within this period then node A once again needs to backoff from contending for the channel.

### *B. Related Works*

Many researches such as [5], [7] and [8] have been carried out to enhance the performance of the communication in terms of throughput, delay, fairness as well as scheduling in various network environments. Such researches successfully provide the services with the desired quality in the above terms. Most of the work that has been carried out by these researches are with single hop centrally controlled network. Another work [12] carried out to find the impact of IEEE 802.11 MAC strategies on multi hop WMN. The paper mainly compares the different MAC in different scenarios. All these researches are mainly concerned with the different approaches to enhance the performance of the network.

The works done by [7], [8] and [9] focus on block ACK in the environment with channel errors. The work in [7] is on centralized system whereas in [8] and [9] is on distributed ad hoc network and noisy channels. Both centralized and distributed system considered the single hop environment. [5] also worked on the block ACK in distributed admission control for controlling the flows to give higher priority traffic use channel.

Emma Carlson et al. [10] researches on end to end resource reservation for the transmission of data in the multi-hop mesh networks. Their communication concludes in two steps. First the reservation period where the route is traced to the destination and whole of the routing path is reserved for the communication. In second phase, actual data transmission takes place. They have achieved constant throughput for all the traffic and almost negligible delay in overall communication which is obvious as entire path is reserved for it.

Ali Hamidian et al. [11] followed the distributed resources reservation before the actual data transmission. Their idea is to have solution to the hidden terminal problem by informing about communication so that neighboring nodes will restrain the communication within that time period. Their analysis basically focuses on the delay and the jitter factor.

Ali Hamidian et al. [5] also gave solution to tackle the hidden node problem where as for the exposed terminal there is no solution. Their work also focuses on admission control for the different type of data so as to have a fairness among the nodes while looking for communication.

Most of the related work is on the reserving the channel for a communication in a single hop environments with a block ACK. There are some work on distributed multi hop environment but without block ACK. Our work is mainly focused on reserving the channel for block acknowledgement on distributed multi-hop environment. This is not end-to-end channel reservation as other nodes, besides the communicating nodes does get the liberty to transmit data if they posses any. Our work also gives the simple but effective way to handle the exposed/hidden terminal problem by increasing throughput and decreasing delays.

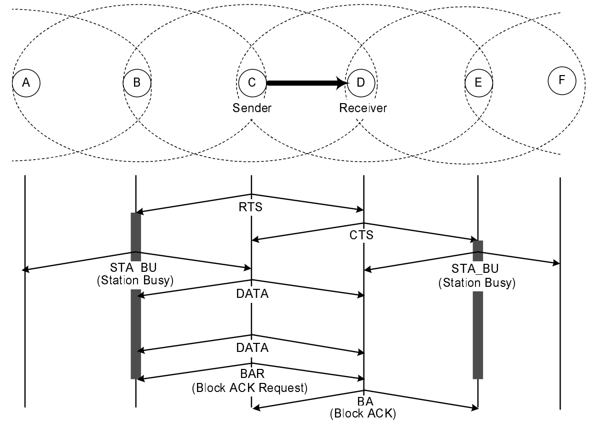



Fig. 2: Aggressive Block ACK Scheme

## III. Proposed Scheme - Aggressive Block ACK Scheme

The inter-wireless MAP/MP communication is via basic 802.11 RTS/CTS mechanism with four way handshake and the access categories defined in 802.11e to virtually control the collision of different types of data. Time critical data stream has the higher priority.

For the block ACK communication the MAP needs to setup the policies. Our approach is to setup the request-to-send (RTS)/clear-to-send (CTS) packets as a distributive system. The RTS packet consists of a basic frame control, RTS duration, source address, destination address, frame check sequence and TXOP request. The CTS packet also consists frame control, CTS duration, source address, and TXOP granted information. TXOP duration is granted depending upon the channel conditions, physical transmission rate, MSDU size as given equation 1 and equation 2 [5].

$$TXOP_i = max\left(\frac{N_i * L_i}{R_i} + O, \frac{M}{R_i} + O\right) \quad (1)$$

where $N_i$ is a number of MAC State Data Units (MSDU) of stations $i$ during one Service Interval (SI), $L_i$ is a nominal MSDU size, $M$ is maximum MSDU size, $O$ is an overhead which is basically the time delays, and $R_i$ is a physical transmission rate of the communication.

$N_i$ is calculated by

$$N_i = \left\lceil \frac{SI * \rho_i}{L_i} \right\rceil \quad (2)$$

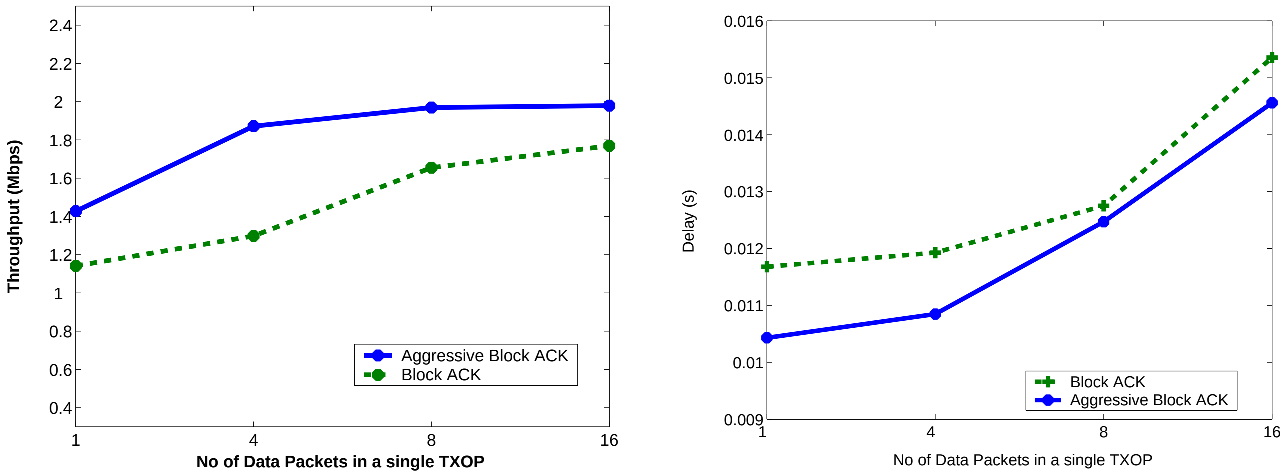
where $SI$ is a Service Interval and $\rho_i$ is the mean data rate. Service Interval (SI) is evaluated using the active transmission period available for the communication which is different for each communication.

The neighboring 1-hop MAP of source (MAP C) and destination (MAP D) hear the exchange of RTS/CTS packets. The final TXOP information granted by the destination is relayed to the 2-hop neighbors by a special control frame called station busy ($STA\_BU$). This packet contains the TXOP duration of the communication so that any packet generated between this period reroutes via different path avoiding the collision.

1-hop neighbor of both source (MAP C) and destination (MAP D) broadcasts the $STA\_BU$ signal as shown in Fig. 2. The destination neighbors, MAP E will broadcast the $STA\_BU$ packet after hearing CTS packet from MAP D and waiting for SIFS time and a small random time period. All the MAPs hearing this $STA\_BU$ will log the sender of the packet. Random time period for transmitting $STA\_BU$ is chosen to avoid collision among the 1-hop neighbors transmitting the same packet. The 1-hop neighbor of the source, MAP C will wait for CTS duration, two SIFS time period and a small random time after hearing the RTS transmission. Actual data transmission is delayed for SIFS and $STA\_BU$ time period which is very small and will not affect the performance of the network.

The MAP A and MAP F is also the 1-hop neighbor of the MAP C and MAP D since they are source and destination for the ongoing communication they will not transmit $STA\_BU$. After 2*SIFS + $STA\_BU$ duration, MAP B will start transmitting multiple data packets to the MAP D with SIFS time between each data packets. Our results are based on the immediate block ACK policy. After finishing the transmission the MAP C will send the block ACK request to the MAP D which on reply will send block ACK (BA) packets with the status of all the received packets within this TXOP period. If any of the data packets are lost then its status is shown in BA. All the lost packets are sent according to the immediate block ACK policy. This policy gives instant reply to the condition of the data transmitted and requires less memory to handle as MAPs don't have to store the status of the data for a long period of time. After the expiry of the TXOP time all the neighboring MAPs will contend for the channel if they have data to transmit.

As in the immediate block ACK policy, if any packet is lost in the course of transmission it can be retransmitted during the same or different TXOP periods depending upon the packet left in the network. The retransmission of the lost packets are sent in next transmission with other fresh data packets or




(a) Average throughput of Grid topology

(b) Delay of the traffic at the different TXOP regions

Fig. 3: Throughput and delay analysis at different number of data packets in a single TXOP

together with the other lost/missed data packets [7]. In the mean time if the 2-hop neighbors of MAP A and MAP F need to transmit the data then they should either wait for the TXOP to expire or communicate via different nodes except the nodes which have informed about the ongoing communication among source and destination via $STA\_BU$. The 2 hop nodes keep the log of the $STA\_BU$ senders. This is going to save long backoff timing as the 2-hop neighbors do not receive any messages form MAP C or MAP D. This feature is mainly used for the hidden terminal problem. In our simulation the packet is rerouted via other MAPs which are not in $STA\_BU$ logs. If all the neighboring MAPs are busy then the communication is paused until an idle channel is sensed. Certain level of fairness is achieved by using the idle path for new transmission.

## IV. Performance Evaluation

We implemented the proposed scheme of aggressive block ACK in ns-2 version 2.28 [14] with the IEEE 802.11e EDCF patch from [13]. The code is modified for the block ACK scheme and implemented our scheme. On the basic of the above scheme the simulation is carried out.

### A. Simulation Environment

Linear and grid topology are used with different number of nodes for our aggressive block ACK scheme. All the nodes in the network represents the Mesh Access Point (MAP). All MAPs have single channel as defined in IEEE 802.11b radios supports different data rates. In our simulation, the channel is tuned for the 5.5Mbps rate for the data and the 1Mbps basic rate for control packets. Each simulation is scheduled for 50sec and is repeated for 5 times to get the normalized results. Transmission range of each MAP is taken 200 meters and the interference range is set for 400 meters, double the transmission range. Transmission range - a range in which a transmitted packet by the sender can be decoded by the receiver - is uniform for all MAPs. If MAPs within this transmission range try to initiate any transmission then there will be an interference to ongoing communication causing a transmission failure due to collision and/or packet loss.

The basic communication between MAPs is carried out with the RTS/CTS exchange. Constant bit rate (CBR) traffic with user datagram protocol (UDP) is considered with CBR packet size of 2000 bytes. Each traffic is generated with different inter-arrival time from 0.001s to 0.01s. The maximum network size is taken as 800m*800m and sources and destinations are chosen randomly with different hop counts for the transmission. There are distinct sources and destinations for the each flow. All the path are equally probable for the communication.

### B. Simulation Results

The results from different simulation scenarios were recorded for analysis. Fig. 3a shows a performance of Aggressive Block ACK compared with the basic block ACK of IEEE 802.11e and shows Aggressive block ACK performed better in terms of throughput and delay. The maximum throughput from our aggressive block ACK is about 60% increment, whereas the average difference in the throughput is about 30%. In a single hop environment and no neighboring communication is going on this difference is minimum. In the linear topology, the overall performance is not much of a difference as there was very little interference from ongoing transmission.

In the Grid topology, different MAPs are taken for the simulations. Within the network, MAPs were randomly picked up for the communication. Fig. 3a shows the Aggressive Block ACK has a better throughput than that of the basic block ACK scheme. The best result was achieved when the traffic had minimum interferences in the path with higher TXOP limit. If the traffic streams were not within the interference region, performance characteristics for both schemes were similar. Time reserved for the single data transmission does not show any substantial difference between our scheme and basic block ACK scheme. As the flow and network size increases the basic phenomenon is that the throughput should decrease due to the interference of the traffic from the neighboring MAPs. These caused the reduction in the throughput. In our implementation, this case is still visible as the throughput decreases with the increase in network flow. Basic block ACK has no information on the ongoing traffic in the neighbor so it causes the decrease in throughput. This is minimized by our implementation where the neighboring nodes have the knowledge of ongoing communications and the time duration of it. This is well visible in the Fig. 3a.

In the larger network, the throughput is bit lowered as the communication due to the increased interference of the neighboring communications. This is a drawback of the larger networks. The MAPs in the larger network have more interference thus decreasing the network throughput. Though the decrement in the throughput is experienced the overall performance of our system is better than the basic Block ACK scheme.

Another aspect to judge the performance is the delay parameter of the network. In Fig. 3b, the delay graph is shown with the different TXOP values. As it can be see the delay of the basic BACK scheme varies with the TXOP limits. The higher the TXOP, higher is the delay factor. It is obvious that if the TXOP is higher more data is required to send in single RTS/CTS transmission. This means that data is delivered only after complete transmission of all data. The delay in our scheme is also visible but it is less than that in the block ACK. The substantial decrease is seen at the lower data count because the data has shorter waiting time. As the number of data packets increases the waiting time is longer so the difference between basic block ACK and our scheme is reduces.

For the fairness in our scheme, let us consider the scenario where MAP A is willing to initiate a communication via MAP B as shown in Fig. 2. MAP A send RTS packet and waits for CTS reply from MAP B. Since MAP B is in locked state it cannot reply to MAP A. This problem is well known as the exposed terminal problem. Many solutions have been proposed for tackling this. In our case this problem is solved by the $STA\_BU$ message which preinforms other MAPs about the ongoing communication with MAP C. This information leads MAP A to redirect its packet to the different MAP so that the MAP A need not wait long or even wait for the channel to be freed if a different route is possible. If the $STA\_BU$ is not provided then the MAP A will go into backoff state by increasing its backoff timer every time it fails to start communication.

During this time if the communication channel is freed then this MAP still need to finish its backoff timer before it can send any RTS packet. This will lead to more unfair situation due to exposed/hidden terminal problem. With the use of the block ACK the situation is much more severe. With the introduction of the $STA\_BU$ little overhead of control packet is added. This packet is a fixed size packet where it gives information about the time required to finish on going transmission so it will not be affecting much the ongoing communication. The Fig. 3 shows no degradation in throughput and delay while using this control packet and performed better than block ACK scheme.

## V. Conclusion

In this paper, we present the classical problem of hidden/exposed terminal problem using block acknowledgement. The problem is severe if block ACK is used for the communication. The approach that we took to solve this problem is simple but effective. The performance evaluation section displays an increase in throughput and decrease in delay which are considered as a basic tool in monitoring the performance of the network. On solving this hidden/exposed terminal, the fairness issue for the nodes to initiate the transmission is also handled. With our technique using block ACK scheme in WMN can lead to equal and fair chances of utilizing the channel for the communication if it is free.

## References


[1] IEEE P802.11s/D1.00, Draft Amendment to Standard for Information Technology - Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Amendment: ESS Mesh Networking, November 2006

[2] I. F. Akyildiz, X. Wang, and W. Wang, "Wireless Mesh Networks: A Survey," Computer networks Journal, vol. 47, pp. 445-487, 2005.

[3] Bernhard H. Walke, Stefan Mangold and Lars Berlemann, "IEEE 802 Wiress Systems protocols, multi-hop Mesh/relaying, perfomance and spectrum coexistence", John Wiley and Sons ltd., 2006

[4] IEEE 802.11e, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Medium Access Control Quality of Service Enhancements, Suppliment to IEEE Std 802.11, November 2005

[5] Ali Hamidian and Ulf Korner, "An Enhancement to the IEEE 802.11e EDCA providing QoS Gurantees," Springer Science + Business Media, LLC 2006

[6] Tourrilhes J., "Packet Frame Grouping: Improving IP multimedia performance over CSMA/CA," Proc. of ICUPC 1998

[7] Hyewon Lee, Ilenia Tinnirello, Jeonggyun Yu, and Sunghyun Choi, "Throughput and Delay Analysis of IEEE 802.11e Block ACK with Channel Errors", IEEE Communication System Software and Middleware (COMESWARE), January 2007

[8] Tianji Li, Qiang Ni, Thierry Turletti, and Yang Xiao, "Performance Analysis of the IEEE 802.11e Block ACK Scheme in a Noisy Channel", IEEE Broadnet, October 2005

[9] Tianji Li, Qiang Ni, and Yang Xiao, "Investigation of the block ACK scheme in wireless ad hoc networks", Wireless communication and mobile computing, 2006

[10] Emma Carlson, Christian Prehofer, Christian Bettstetter, Holfer Karl, and Adam Wolisz, "A Distributed End-to-End Reservation Protocol for IEEE 802.11 based Wireless Mesh Networks", JSAC, November 2006

[11] Ali Hamidian and Ulf Korner, "Providing QoS in Ad Hoc networks with Distributed Resource Reservation", ITC-20, 2007

[12] Seongkwan Kim, Sung-Ju Lee, and Sunghyun Choi, "The Impact of IEEE 802.11 MAC Strategies on Multi-Hop Wireless Mesh Networks", IEEE Wireless Mesh Networks (WiMesh), September 2006

[13] Sven Wietholter, Christian Hoene, "Design and Verification of an IEEE 802.11e EDCF Simulation Model in 2003", TKN Technical Reports Series, November 2003
url: $http://www.tkn.tu-berlin.de/research/802.11e\_ns2/$

[14] www.isi.edu/nsnam/ns/